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FLIGHT EVALUATION OF THREE TECHNIQUES OF DEMONSTRATING THE MINIMUM FLYING SPEED OF A DELTA-WING AIRPLANE

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SUMMARY

A flight-test program was conducted with an F5D airplane to evaluate three techniques for demonstrating the minimum flying speed of a delta-wing aircraft: the Civil Air Regulations stall-speed demonstration, the 1 g demonstration, and the constant-rate-of-climb demonstration.

The Civil Air Regulations stall-speed demonstration currently used for civil transport aircraft was found to be inadequate for demonstrating the minimum speed of a delta-wing airplane, because this type of airplane does not have a well-defined stall point near the maximum lift coefficient. The 1 g minimum speed, which is based on maintaining a constant 1 g normal acceleration, was difficult to determine precisely, especially when buffeting was present. The constant-rate-of-climb minimum-speed maneuvers, which are based on the ability to maintain a constant rate of climb, were reasonably easy to perform and were unaffected by the aircraft buffet characteristics. The level-flight minimum speed obtained from the constant-rate-of-climb technique was found to be the most rational minimum speed for a delta-wing aircraft. The applicability of these techniques to other types of aircraft was shown in limited tests on a sweptwing airplane.

INTRODUCTION

The minimum flying speed of an aircraft influences takeoff, climbout, approach, and landing speeds which, in turn, determine runway requirements and payload capability. Thus, proper determination of the minimum speed is of prime importance in the evaluation of an aircraft.

The minimum flying speeds of civil transports are currently defined by the Civil Air Regulations (CAR) stall speed (ref. 1). This definition was adequate until the advent of airplanes with highly swept and delta wings. The traditional "stall" is not a well-defined point for these airplanes and is not a significant factor in determining the minimum speed.

A program was conducted with an F5D delta-wing airplane at the NASA Flight Research Center, Edwards, Calif., to evaluate two alternate techniques of demonstrating the minimum speed and to compare these techniques with the existing CAR stall-speed demonstration. One of the techniques investigated is based on the ability to maintain a constant 1 g normal acceleration while decreasing speed; the other is based on the ability to maintain a constant rate of climb (including level flight) while decreasing speed. The applicability of these techniques to other types of airplanes was investigated in limited tests with a JetStar airplane.

The minimum speed of an aircraft is dependent on many factors, including stability, control, and landing attitude. This study considers only the aircraft-performance aspect, that is, limitation of the minimum speed by the maximum lift capability of the aircraft. In evaluating the three demonstration techniques, the following basic requirements were considered: (1) the minimum speed should not correspond to an angle of attack significantly greater than that at maximum lift coefficient; (2) the minimum speed should be reasonably easy to demonstrate, reproducible, and not require any unusual piloting technique; and (3) the technique should be applicable to all types of airplanes.

SYMBOLS

a_n	normal acceleration, g
C_D	coefficient of drag
C_L	coefficient of lift
$(C_L)_{max}$	maximum lift coefficient
D	drag, lb
g	acceleration of gravity, ft/sec^2
h	altitude, ft
$\dot{h}$	rate of climb, ft/min
L	lift, lb
L/D	lift-drag ratio
S	wing area, sq ft
T	thrust, lb
t	time, sec
$\dot{V}$	rate of change of velocity with time $\frac{dV_i}{dt}$, knots/sec
V_i	indicated airspeed, knots

V_{min} minimum indicated airspeed, knots

V_s CAR stall speed, knots

V_t true airspeed, knots

W airplane gross weight, lb

X,Z longitudinal and vertical body axes, respectively

X_w,Z_w longitudinal and vertical wind axes, respectively

α angle of attack, deg

β angle of sideslip, deg

γ flight-path angle, deg

ϵ angle between accelerometer axis and aircraft body axis, deg

θ pitch angle from horizontal, deg

ρ atmospheric density, slugs/cu ft

ρ_0 standard sea-level density, 2.38×10^{-3}, slugs/cu ft

Superscript:

* values at maximum lift coefficient

TEST AIRPLANE

The F5D airplane is a single-place, high-performance fighter interceptor powered by a J57 turbojet engine with afterburner. The airplane has a modified delta wing with rounded tips and leading-edge slats. A three-view drawing and a photograph are shown in figures 1 and 2, respectively. Physical characteristics are presented in table I, and the low-speed aerodynamic lift and drag characteristics obtained from unpublished wind-tunnel data are shown in figure 3.

Aircraft control is provided by irreversible hydraulically powered elevons and rudder with bungee artificial-feel systems. Longitudinal trim is achieved by repositioning the neutral point of the artificial-feel system. Lateral-directional stability is acceptable for angles of attack up to the maximum lift coefficient ($\alpha^* = 25^\circ$) but then decreases rapidly until it is unacceptable at an angle of attack of about 30°. Buffeting is light-to-moderate at the lower speeds.

The tests were conducted in the landing configuration (gear down and leading-edge slats fully extended). The center of gravity was at 23.5 $\pm\frac{1}{2}$ percent mean aerodynamic chord. The wing loading ranged from 33 lb/sq ft to 46 lb/sq ft, and the gross weight varied from 18,400 pounds to 25,800 pounds. All minimum speeds presented herein are corrected to a gross weight of 20,000 pounds.

INSTRUMENTATION

A standard NASA airspeed head was mounted on the nose boom to measure airspeed and altitude. No airspeed-system calibration was performed, inasmuch as the purpose of the study was to compare methods of demonstration rather than to determine the calibrated minimum speed. Angle of attack and angle of sideslip were measured with vanes located on the nose boom. Normal acceleration was measured at the airplane center of gravity. The following quantities were recorded on film with the repeatability shown, and the records were correlated with a common 0.1-second timer:

Indicated airspeed	±0.5 knot
Indicated altitude	±5 feet
Normal acceleration	±0.05g
Angle of attack	±0.25°
Angle of sideslip	±0.25°

The airplane weight was determined from pilot readout of the fuel-quantity gage and is estimated to be accurate to ±100 pounds.

DISCUSSION

Civil Air Regulations Stall-Speed Demonstration

The current Civil Air Regulations stall-speed demonstration for turbine-powered transport aircraft (ref. 1) consists of a series of maneuvers which establishes the stall speed corresponding to a deceleration of less than 1 knot per second. The maneuvers are performed by decelerating at a constant rate down to the stall with a specified configuration and power setting. During each maneuver, the deceleration is maintained by varying the rate of climb while the angle of attack is continuously increasing. Since the minimum speed is a function of deceleration $\dot{V}$, the speed corresponding to a deceleration of 1 knot/sec (for turbine-powered aircraft) is used as the demonstrated stall speed. This speed is obtained by plotting minimum indicated airspeed V_{min} as a function of deceleration for several maneuvers.

The stall speed of the test airplane was demonstrated by trimming at a speed 40 knots to 60 knots higher than the predicted minimum speed, reducing the power to a specified level, and establishing a constant deceleration which was maintained until the maneuver was terminated. A time history of a typical maneuver is shown in figure 4. During this maneuver, a relatively constant deceleration of 1.9 knots/sec was maintained until termination of the test. The lowest speed obtained during the maneuver was 97 knots (94 knots corrected to 20,000 lb gross weight), which occurred at a rate of sink of 5,780 ft/min. The maneuver was ended by the pilot because of the decreasing lateral-directional stability and the high sink rate. At no time was there any evidence of a stall even though an angle of attack of 30°, significantly past $(C_L)_{max}$, was reached. This speed, then, is actually a minimum control speed rather than a stall speed. The minimum speeds obtained from a series of these maneuvers are plotted in figure 5 as a function of $\dot{V}$ (the method used in the CAR stall-speed analysis), and a speed of 101 knots is obtained at $\dot{V} = -1$ knot/sec.

Without a well-defined stall point, the minimum speed of the test airplane as demonstrated by the CAR technique corresponds to an angle of attack significantly greater than that at $(C_L)_{max}$, a condition that is not attainable in normal steady-state operation. The demonstration, itself, is inherently dangerous because of the high rates of sink that are required to maintain a deceleration of less than 1 knot/sec. Thus, the stall point cannot be used as a means of defining minimum speed for any aircraft that does not have a well-defined stall point near the maximum lift coefficient.

1 g Minimum-Speed Demonstration

The 1 g minimum speed is defined as the lowest speed an aircraft can attain while maintaining 1 g flight. The maneuver used to demonstrate this speed is similar to the stall-approach maneuver, except that the pilot uses a cockpit accelerometer to maintain the desired flight conditions. A range of decelerations is obtained by varying the initial rate of climb. The procedure used was to trim at a speed about 40 knots above the minimum speed with a given rate of climb in the range of ±1,000 ft/min. The power was then reduced and held constant at the desired level. A range of thrust-weight ratios from 0.02 (idle thrust) to 0.15 was covered. As the aircraft decelerated to the minimum speed, the pilot maintained 1 g flight by using the cockpit accelerometer. Flight records were obtained from an accelerometer mounted at the airplane center of gravity. Both accelerometers were mounted along the aircraft body axes.

A time history of a constant 1 g maneuver is shown in figure 6. The pilot was able to maintain 1 g flight until $t = 16$ seconds, at which time the velocity was 109.5 knots (106.8 knots corrected to 20,000 lb gross weight). Figure 7 presents data from a maneuver in which 1 g flight was lost near maximum lift coefficient ($t = 18$ sec), regained, and then finally lost at $t = 21.5$ sec where the angle of attack was greater than that for $(C_L)_{max}$. As a result, the minimum speeds obtained from the 1 g technique were determined from the last point at which a continuous 1 g normal acceleration could be maintained, rather than from the last point at which it was obtainable.

The equation for predicting the 1 g minimum speed for an aircraft with an accelerometer mounted perpendicular to the fuselage reference line or body axis is developed in the appendix (eq. (5)). This equation shows that the minimum speed is a function of the angle of attack and lift-drag ratio at the maximum lift coefficient, as well as of the maximum lift coefficient, and is not a function of the flight-path angle or thrust. The equation for the minimum speed when an accelerometer is mounted along an axis perpendicular to the flight path or wind axis at $(C_L)_{max}$ (eq. (6), appendix) shows that an accelerometer mounted in this fashion would be acted upon by the lift force and a component of the thrust and would not be affected by any component of the drag force.

With either method of mounting the accelerometer, the 1 g minimum speed is not a function of the flight variables $\dot{h}$ or $\dot{V}$ as used in the conventional stall-speed analysis. Consequently, the 1 g minimum-speed technique consists of demonstrating a single point, and the ultimate speed defined must be determined from a numerical average rather than a graphical average of several maneuvers over a range of flight variables.

The minimum speeds obtained in the 1 g maneuvers are summarized in figure 8(a) as a function of the rate of climb at the minimum speed. Figure 8(b) presents the same data in terms of the more familiar $\dot{V}$ plotted against V_{min}, as used in the CAR stall-speed analysis. Also shown in both figures is the calculated value of V_{min}. The test data verify that the 1 g normal acceleration minimum speed is independent of T, $\dot{h}$, and $\dot{V}$ as predicted from equation (5) in the appendix for V_{min}. However, the data show only approximate agreement with the calculated value, with most of the V_{min} points about 4 knots higher than predicted. From the time histories of these maneuvers, it was noted that the break from a constant 1 g normal acceleration occurred in the region where the lift-curve slope (fig. 3) changes rapidly, approaching $(C_L)_{max}$. It would appear that, with sufficient pilot practice, it may be possible to pass through this region to maximum lift coefficient while maintaining 1 g flight; thus, the minimum speeds would approach the calculated values.

Constant-Rate-of-Climb Demonstration

The constant-rate-of-climb minimum speed is defined as the lowest speed that an aircraft can attain while maintaining a specified rate of climb. The demonstration of this speed consists of a deceleration to the minimum speed while the pilot maintains the aircraft at a constant rate of climb by referring to the cockpit indicator. The maneuvers were performed with the test airplane at various rates of climb from 1,800 ft/min to -2,200 ft/min. Most of the maneuvers were made at idle thrust, although several were made at a thrust-weight ratio of 0.15 to verify the effects on V_{min}.

Two typical rate-of-climb maneuvers are shown in figures 9 and 10 for rates of climb of 900 ft/min and -2,080 ft/min, respectively. Noted in the figures are the last points at which the rate of climb could be held constant. In both maneuvers the pilot was able to maintain a constant rate of climb until an angle of attack near 25° ($(C_L)_{max}$) was reached. The data show that the break in the rate of climb could be determined to the nearest $\frac{1}{2}$ second by using altitude data plotted to the nearest 5-foot increment.

The equation defining the constant-rate-of-climb minimum speed is developed in the appendix (eq. (7)). This equation shows that the minimum speed is a function of the rate of climb, lift-drag ratio, pitch angle, thrust, and the maximum lift coefficient. Since increasing the thrust decreases the minimum speed, the choice of the zero-thrust condition provides the most conservative minimum speed. As shown in sketch (b) in the appendix, the optimum rate of climb is 0 (level flight), since it is only at this point that the minimum speed is independent of the lift-drag ratio.

The use of level flight, or zero rate of climb, has been presented previously as a definition of minimum speed (ref. 2, for example), but, as with the 1 g minimum-speed technique, a convenient method of demonstrating this single point in flight has not been available. An analysis similar to that used in the CAR stall-speed determination can be accomplished, however, by performing a series of maneuvers in the desired configuration, preferably with zero thrust, at both positive and negative rates of climb. A curve can be faired through the minimum-speed data points plotted as a function of rate of climb to determine the level-flight minimum speed.

A summary of data obtained from the rate-of-climb maneuvers is shown in figure 11 in which V_{min} is plotted as a function of rate of climb for idle thrust and for a thrust-weight ratio of 0.15. Also included is the calculated value of V_{min}. For idle thrust (fig. 11(a)), a faired curve through the data produces a minimum indicated airspeed of 108 knots for the level-flight minimum speed. This value is about 2 knots lower than calculated. The effects of thrust-weight ratio in lowering V_{min} are apparent in figure 11(b), especially at high positive rates of climb. The level-flight minimum speed for the thrust-weight ratio of 0.15 is approximately 4 knots lower than for the idle-thrust condition. From figures 9 and 10, it appears that the transient lift effects normally associated with large rates of change of angle of attack would not be appreciable because of the low rates involved. This effect is substantiated by the agreement of the flight data of figure 11 with the calculated curve where the rate of change of angle of attack was assumed equal to zero. In an effort to reduce the scatter of the data, the standard rate-of-climb meter was replaced with a commercially available meter with an accelerometer quickening device. The lag was greatly reduced and, thus, the pilot was given a nearly instantaneous indication of rate of climb. Although the pilot reported that the maneuver was easier to perform with this meter, the data (fig. 11(a)) show no significant reduction in scatter.

Application of the Techniques to Other Aircraft

One flight was made with a JetStar airplane to compare the constant-rate-of-climb minimum speed and the 1 g normal-acceleration minimum speed with the CAR stall speed. The JetStar is a four-engine, sweptwing transport representative of current civil jet transports. The constant-rate-of-climb maneuvers were conducted in the clean and the approach configurations at idle thrust. The 1 g normal acceleration and the CAR stall tests were conducted in the clean configuration at idle thrust. The miniumum-speed data were obtained at an altitude of 10,000 feet and corrected to a gross weight of 30,000 pounds.

A series of CAR stall-speed maneuvers was performed at various decelerations (fig. 12). As shown in the figure, the stall speed corresponding to $\dot{V} = -1$ knot/sec is 110.5 knots, which agrees with the JetStar flight manual stall speed of 111 knots.

A series of 1 g normal-acceleration maneuvers was also attempted. With the buffet experienced, however, the pilot was unable to perform precise maneuvers using the cockpit accelerometer. Consequently, the maneuver and associated recorded data were not satisfactory for analysis.

Two typical time histories from a series of constant-rate-of-climb maneuvers made at various rates of climb with the JetStar are shown in figures 13 and 14. The previously mentioned buffeting, which invalidated the analysis of the 1 g normal-acceleration maneuver, is illustrated by the normal-acceleration trace. Since the airspeed-altitude instruments were relatively unaffected by buffet, it was possible to perform the constant-rate-of-climb analysis despite the buffeting. A summary of the minimum speeds obtained from these maneuvers is shown as a function of rate of climb in figure 15(a) for the clean configuration and in figure 15(b) for the approach configuration. Also shown is the flight manual stall speed for each configuration. The calculated values of the minimum speed were not included, since accurate aerodynamic data at maximum lift coefficient were not available. The level-flight minimum speed is within 2 knots of the stall speed specified for each configuration. This agreement is believed to be indicative of the results that would be obtained with aircraft that have a well-defined stall point near maximum lift coefficient.

CONCLUSIONS

Three techniques for demonstrating the minimum flying speed of a delta-wing aircraft--the Civil Air Regulations stall-speed demonstration, the 1 g normal-acceleration demonstration, and the constant-rate-of-climb demonstration--were investigated in a flight program. From this study, it was concluded that:

1. The Civil Air Regulations stall-speed demonstration does not provide a satisfactory definition of the minimum speed, inasmuch as delta-wing aircraft do not have a well-defined stall point near the maximum lift coefficient.

2. The 1 g normal-acceleration minimum speed cannot be readily determined since it is not a function of the rate of change of velocity or rate of climb. From a piloting standpoint, the 1 g maneuver is difficult to perform precisely and, with heavy buffeting, cannot be performed satisfactorily by using a standard cockpit accelerometer.

3. The level-flight minimum speed is the most rational minimum speed for a delta-wing airplane.

4. The level-flight minimum-speed demonstration can be accomplished by performing a series of constant-rate-of-climb maneuvers. These maneuvers are reasonably easy to perform and are unaffected by the buffeting characteristics of the airplane.

5. The constant-rate-of-climb technique is also applicable to sweptwing airplanes.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., March 23, 1964.

APPENDIX

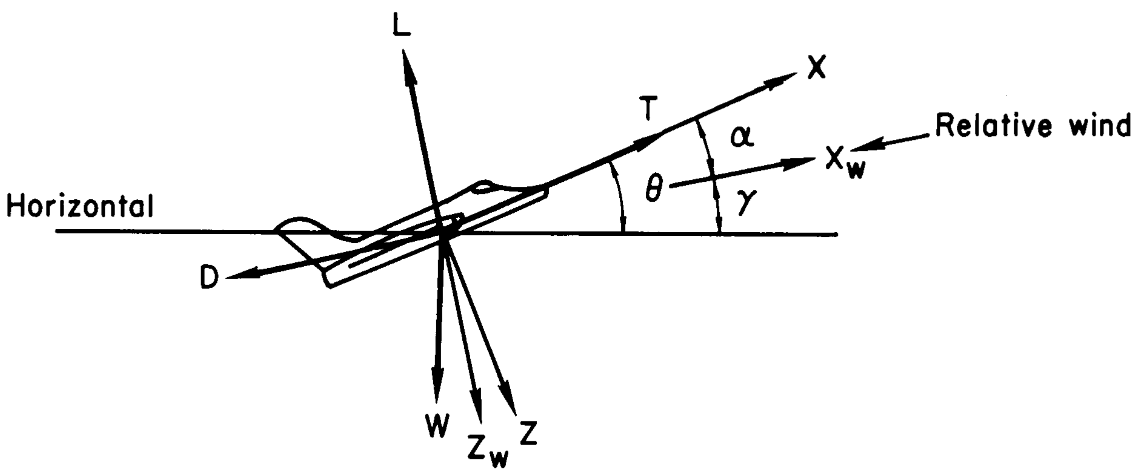
DERIVATION AND APPLICATION OF ANALYTICAL EXPRESSIONS FOR THE MINIMUM-SPEED MANEUVERS

The following derivations are made for an aircraft in quasi-steady-state conditions. Only the two-degree-of-freedom performance problem is considered, and no allowance is made for control effectiveness, moments, or transient effects such as transient lift. During the maneuver, the weight is considered to be constant and the thrust is assumed to be a constant force acting along the fuselage reference line. For the calculation of minimum indicated airspeed V_{min}, the airspeed position and instrument errors are assumed to be negligible so that $V_i = V_t\sqrt{\frac{\rho}{\rho_0}}$.

1 g Normal-Acceleration Maneuver

For the 1 g normal-acceleration maneuver with the accelerometer mounted along the body axes, the acceleration along the X-axis is not specified and the summation of forces along the Z-axis (sketch (a)) yields

$$W \cos \theta - L \cos \alpha - D \sin \alpha = \frac{W}{g} a_n \tag{1}$$



Sketch (a)

An accelerometer mounted along the body axes reads $g \cos \theta - a_n$ which must equal 1 g so that

$$a_n = g \cos \theta - g \tag{2}$$

Substituting equation (2) into equation (1) and simplifying

$$L \cos \alpha + D \sin \alpha = W \tag{3}$$

Substituting for L and D in terms of their coefficients and solving for V_i^2

$$V_i^2 = \frac{2W}{\rho_0 S}\left(\frac{1}{C_L \cos \alpha + C_D \sin \alpha}\right) \tag{4}$$

or rearranging and substituting for the values at $(C_L)_{max}$

$$V_{min} = \left[\frac{2W}{\rho_0 S (C_L)_{max}}\left(\frac{1}{\cos \alpha^* + \frac{\sin \alpha^*}{(L/D)^*}}\right)\right]^{1/2} \tag{5}$$

The 1 g minimum speed is sensitive to α^* and $(L/D)^*$, which are functions of the configuration, because an accelerometer mounted along the body axes is acted upon by the normal force producing a "normal" 1 g acceleration. The normal force consists of the lift and drag components perpendicular to the body axes and does not contain a thrust component if the thrust axis is along the X-axis, as in the test airplane.

An alternate method of mounting the accelerometer is at an angle $\epsilon = -\alpha^*$ from the X-axis which measures the acceleration along the wind axis at $(C_L)_{max}$. The summation of forces along the wind axes X_W and Z_W and the subsequent simplification yields

$$V_{min} = \left[\frac{2W}{\rho_0 S (C_L)_{max}}\left(1 - \frac{T}{W} \sin \alpha^*\right)\right]^{1/2} \tag{6}$$

An accelerometer mounted in this fashion would be acted upon by the lift force and a component of the thrust and would not be affected by a component of the drag force.

Constant-Rate-of-Climb Maneuver

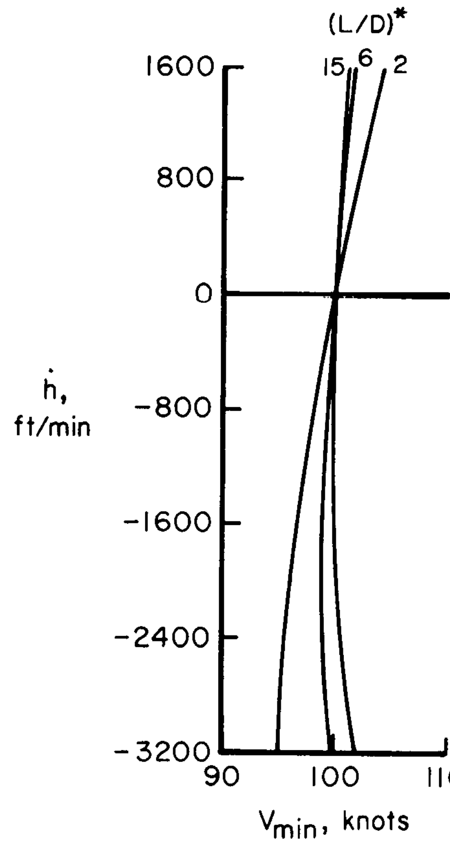
For the constant-rate-of-climb maneuver, a similar solution, summing forces about the horizontal and vertical earth axes, yields

$$V_{min} = \left[\frac{2W}{\rho_0 S(C_L)_{max}}\left(\frac{1}{\cos\gamma - \frac{\sin\gamma}{(L/D)^*}}\right)\left(1 - \frac{T}{W}\sin\theta^*\right)\right]^{1/2} \tag{7}$$

From this expression it is seen that V_{min} is a function of the flight variable $\dot{h}$ (or γ), the configuration variables $(L/D)^*$, θ^*, and $(C_L)_{max}$, and the thrust-weight ratio. Since this equation does not define a unique speed, further restrictions must be placed on the variables T/W and $\dot{h}$ to provide a single definition of the minimum speed.

Equation (7) shows that the effect of the thrust-weight ratio is dependent on θ^* and, since θ^* is always positive for the minimum-speed maneuver, any positive value of T/W has the effect of lowering V_{min}. In order to present the most conservative value of V_{min}, a thrust-weight ratio of zero must be selected.

The theoretical effect of rate of climb on minimum indicated airspeed is shown in sketch (b) for three values of lift-drag ratio at maximum lift coefficient. In the calculations for this sketch, the thrust is assumed to be zero and the quantity $\left(\frac{2W}{\rho_0 S(C_L)_{max}}\right)^{1/2}$ is equal to 100 knots.



Sketch (b)

The sketch shows that V_{min} decreases with increasing rate of descent and also with decreasing $(L/D)^*$. The selection of V_{min} at $\dot{h} = 0$ eliminates the effect of $(L/D)^*$ and thereby provides a common base for all types of airplanes regardless of configuration.

For zero thrust and level flight, it should be noted that equations (6) and (7) reduce to the following expression which does not contain the configuration variables α^* or $(L/D)^*$

$$V_{min} = \left(\frac{2W}{\rho_0 S(C_L)_{max}}\right)^{1/2}$$

REFERENCES

1. Anon.: Civil Aeronautics Manual 4b - Airplane Airworthiness; Transport Categories. Federal Aviation Agency, Sept. 1962.

2. Cheney, H. K.: SST Flight Test Requirements for Certification of Take-off/ Landing Performance. Proceedings of a Symposium on Supersonic Transports, The Soc. of Exp. Test Pilots, Sept. 29-30, 1961, pp. 175-199.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE F5D AIRPLANE

Wing:	
Airfoil section, root	NACA 0005-1.1-30-6° (Modified)
Airfoil section, tip	NACA 0003-1.1-30-6° (Modified)
Area, sq ft	557
Span, ft	33.50
Mean aerodynamic chord, ft	18.25
Root chord, ft	25.08
Tip chord, ft	8.33
Aspect ratio	2.02
Taper ratio	.33
Sweep at leading edge, deg	52.50
Sweep at quarter chord, deg	46.50
Sweep at trailing edge, deg	16.50
Incidence, deg	0
Dihedral, deg	0
Geometric twist, deg	0
Outboard elevon:	
Area (per side), sq ft	24.26
Span (normal to fuselage reference line), ft	11.73
Mean aerodynamic chord, ft	2.04
Maximum deflection, up, deg	40
Maximum deflection, down, deg	20
Inboard elevon:	
Area (per side), sq ft	9.04
Span (normal to fuselage reference line), ft	2.58
Mean aerodynamic chord, ft	3.75
Maximum deflection, up, deg	30
Maximum deflection, down, deg	5
Slat:	
Area (per side), sq ft	7.96
Span, ft	4.56
Mean aerodynamic chord, ft	1.10
Slat chord/wing chord	.13
Vertical tail:	
Airfoil section, root	NACA 0005-1.1-25-6° (Modified)
Airfoil section, tip	NACA 0003.2-1.1-50-6° (Modified)
Area, sq ft	69.87
Span, ft	9.46
Mean aerodynamic chord, ft	7.85
Aspect ratio	1.28
Taper ratio	.46
Sweepback of quarter chord, deg	48.22
Rudder:	
Area, sq ft	9.29
Span (normal to fuselage reference line), ft	6.26
Mean aerodynamic chord, ft	1.23
Upper-wing speed brakes:	
Area (per side), sq ft	3.26
Span, ft	2.38
Maximum deflection, deg	45
Lower-wing speed brakes:	
Area (per side), sq ft	3.26
Span, ft	2.38
Maximum deflection, deg	60
Fuselage:	
Frontal area, sq ft	18.70
Length, ft	53.80
Fineness ratio	7.86
Wetted area, sq ft	466
Test center-of-gravity location, percent mean aerodynamic chord	23.5
Weight:	
Gross, lb	26,100
Empty, lb	17,100

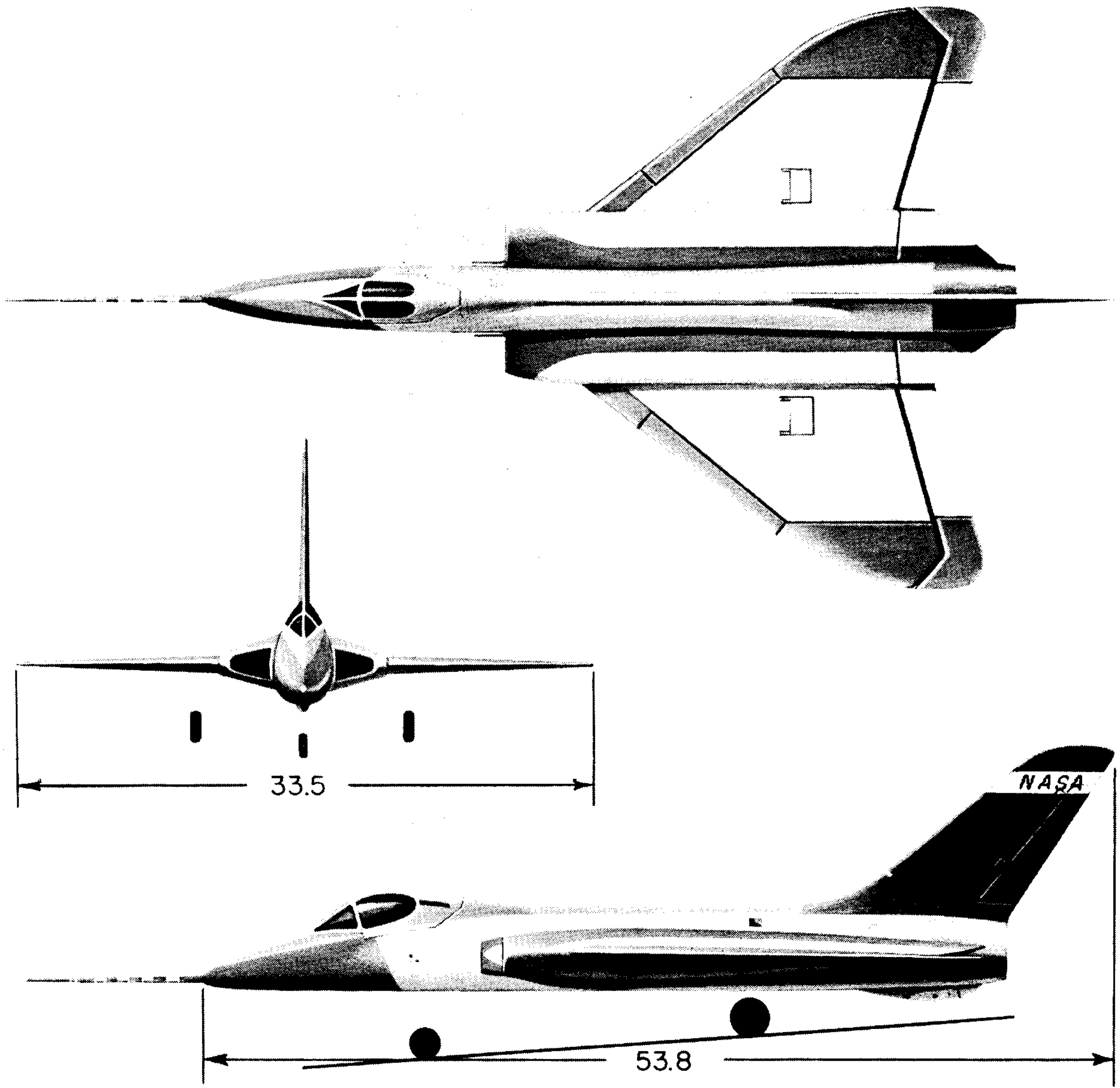


Figure 1.- Three-view drawing of the F5D airplane. Dimensions in feet.

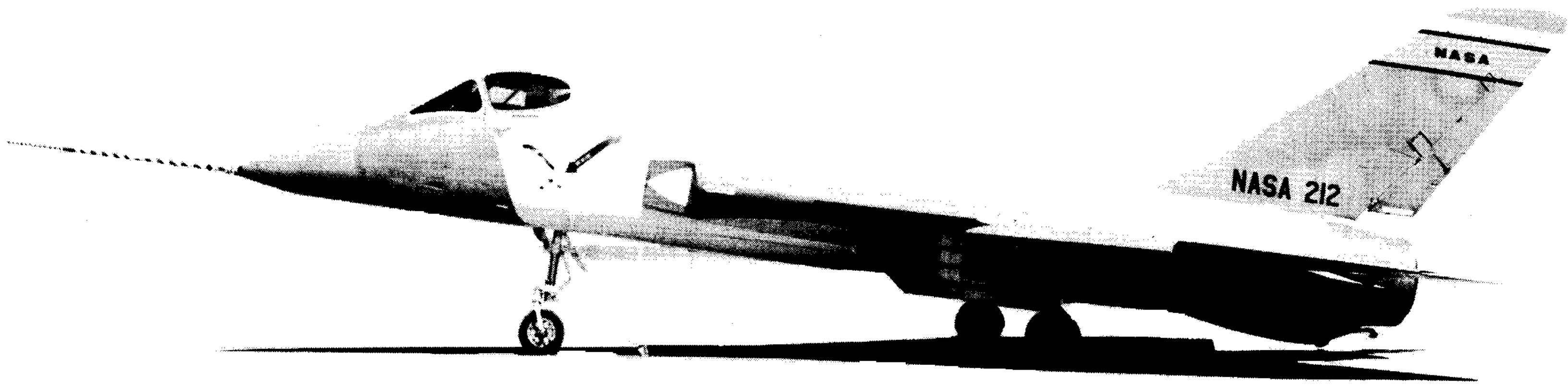


Figure 2.- F5D airplane.

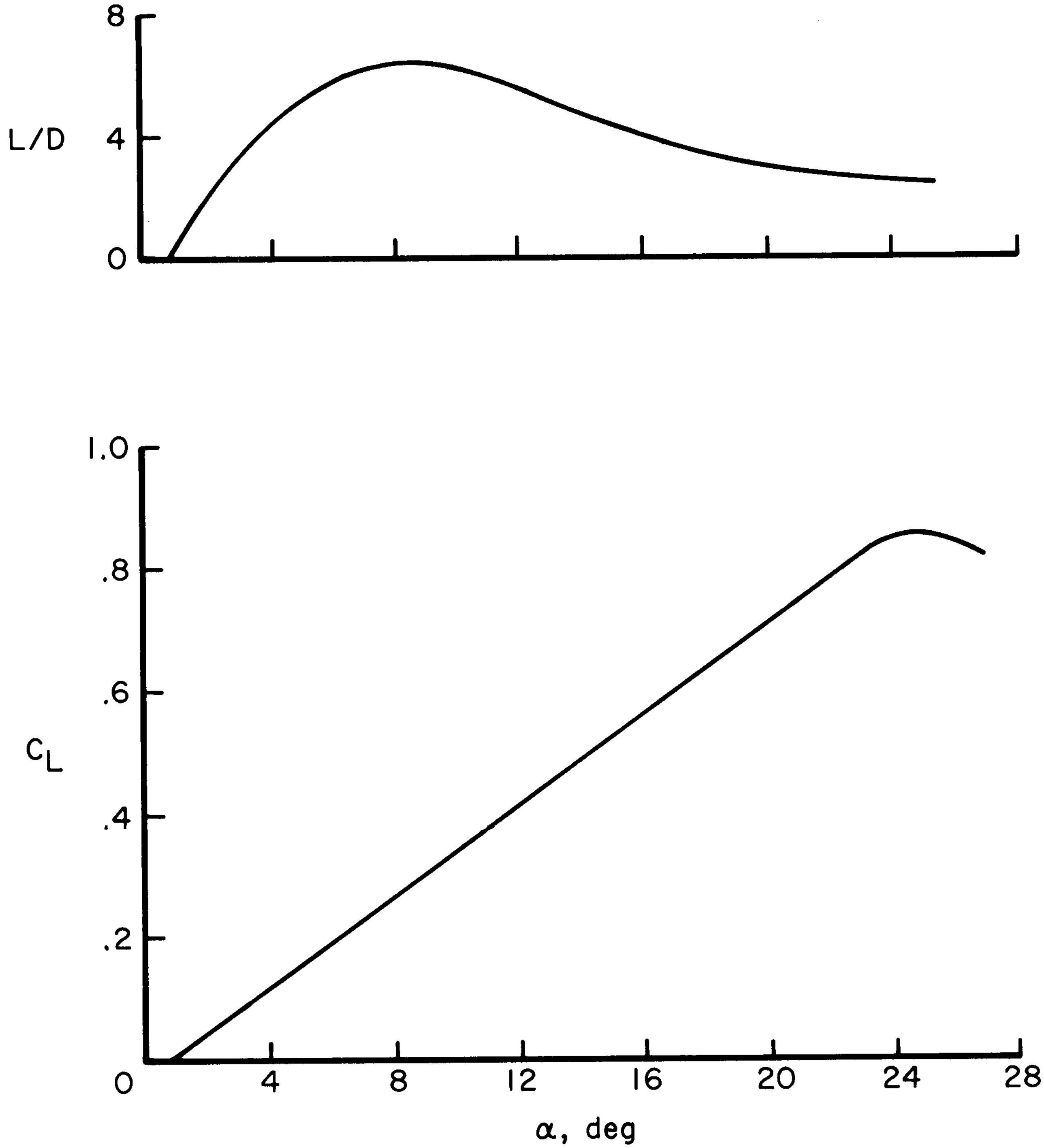


Figure 3.- Low-speed lift and drag characteristics of the F5D airplane in the landing configuration, obtained from wind-tunnel tests.

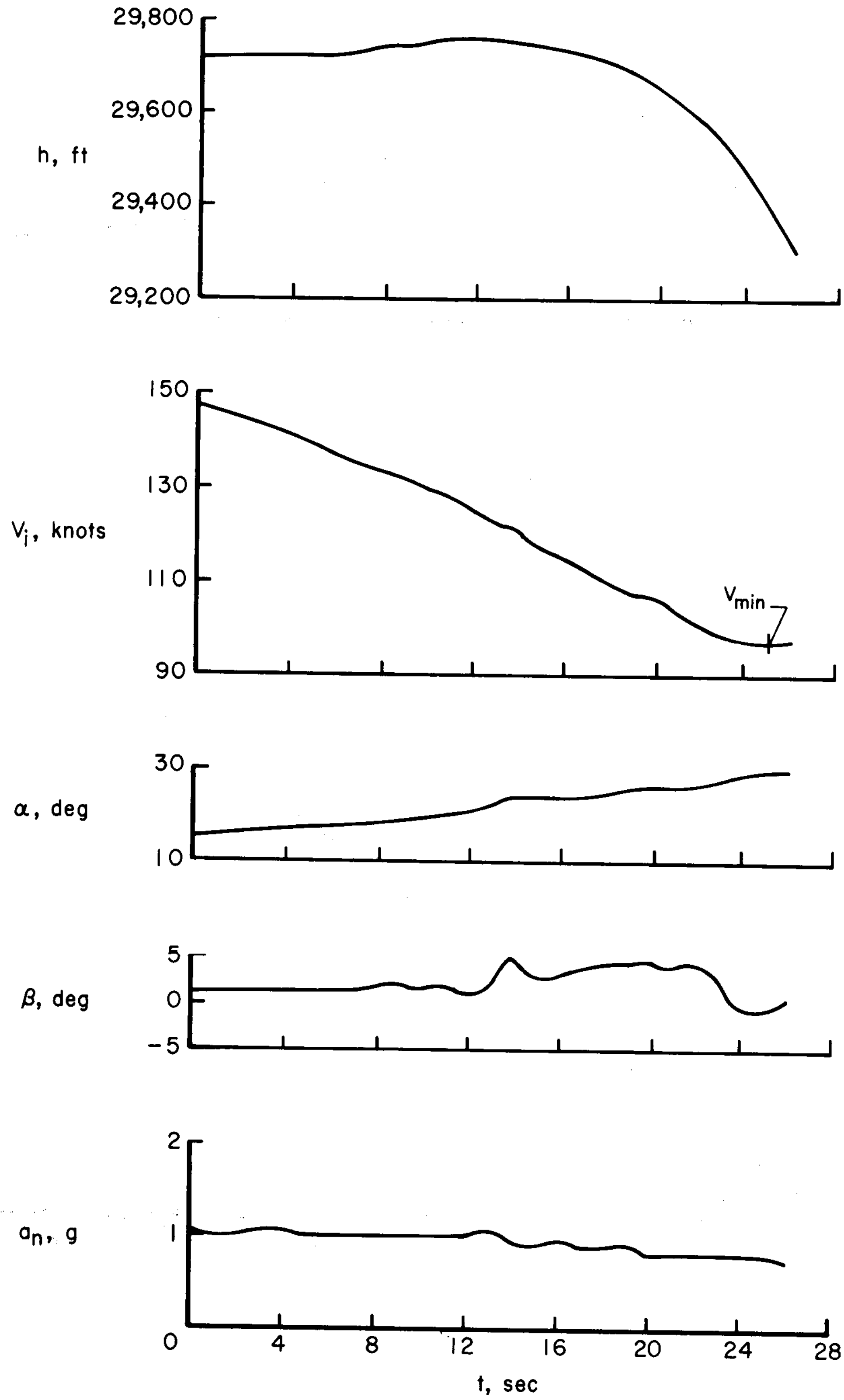


Figure 4.- Typical CAR stall maneuver for the F5D airplane. Idle thrust; 21,300 pounds gross weight.

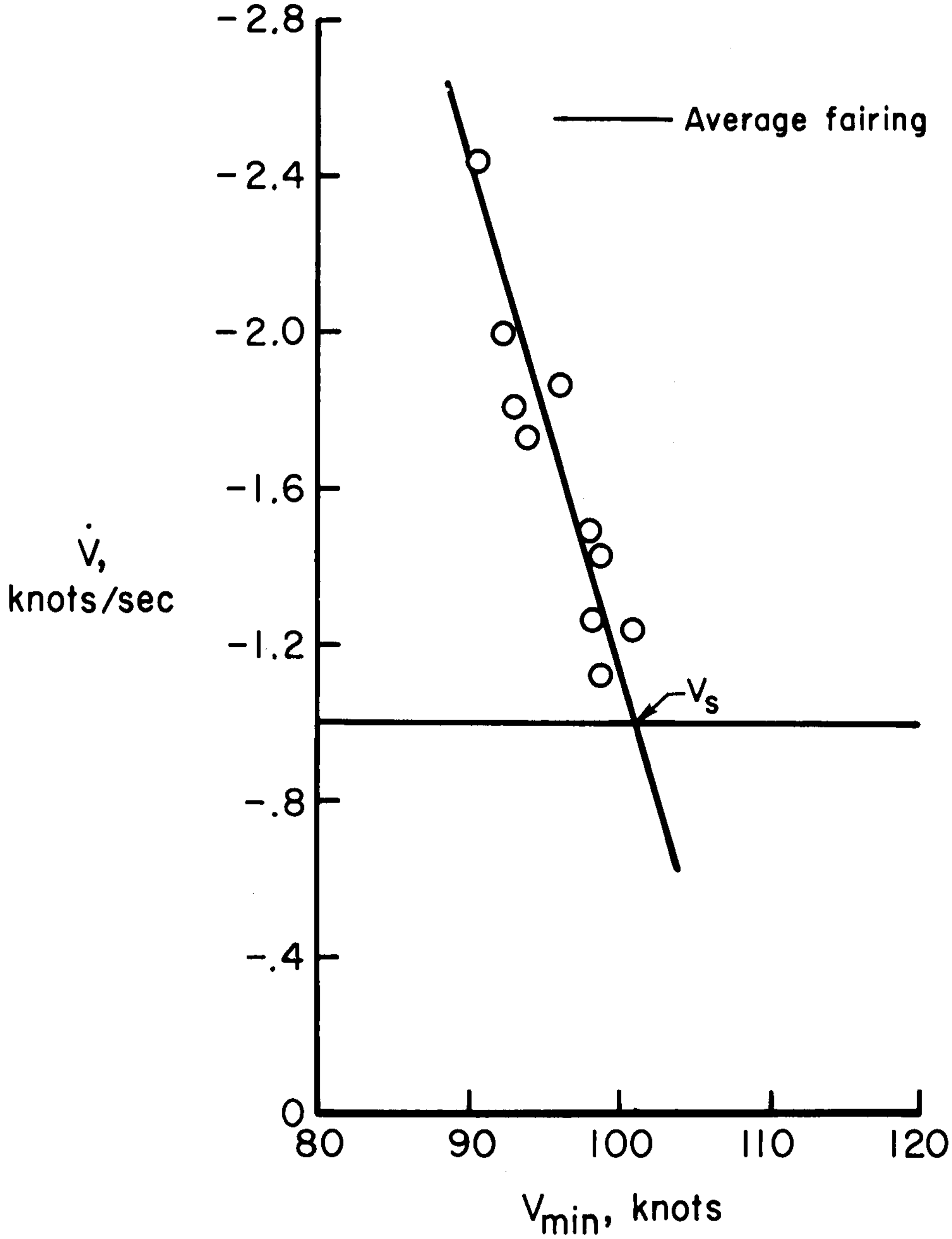


Figure 5.- CAR stall analysis for the F5D airplane. V_{min} corrected to 20,000 pounds gross weight.

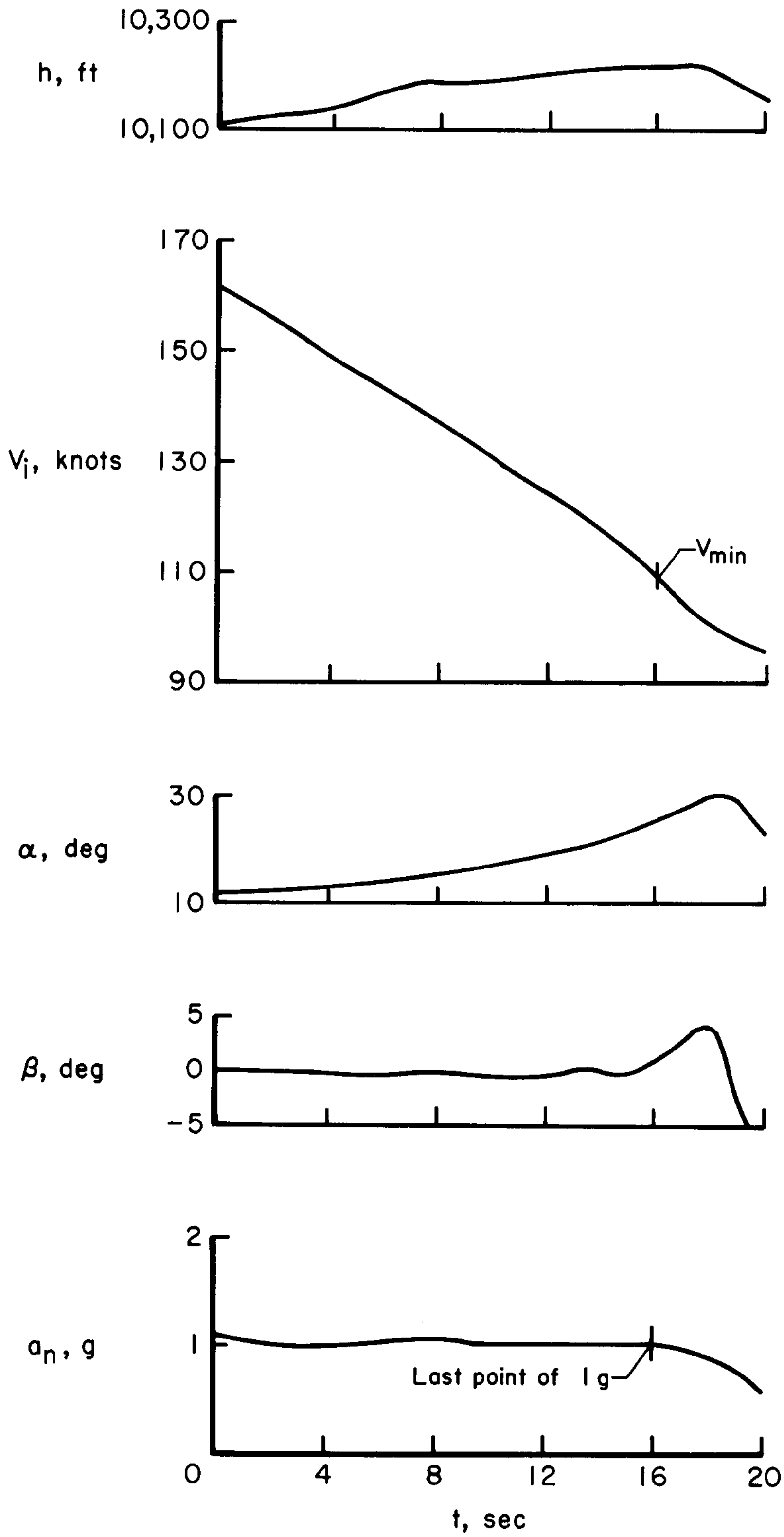


Figure 6.- 1 g normal-acceleration maneuver for the F5D airplane with an initial rate of climb. Idle thrust; 21,000 pounds gross weight. Accelerometer mounted along body axes.

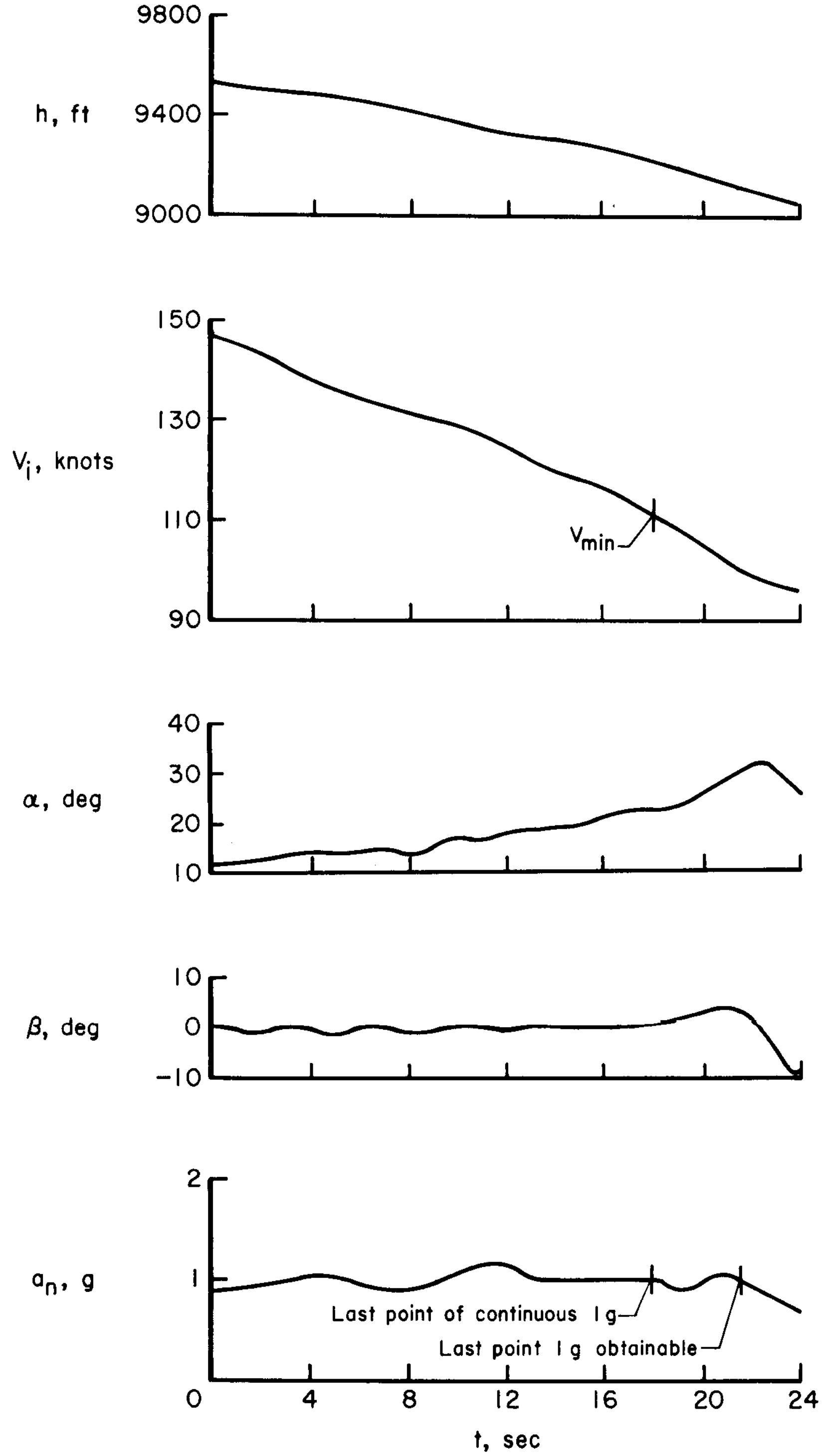
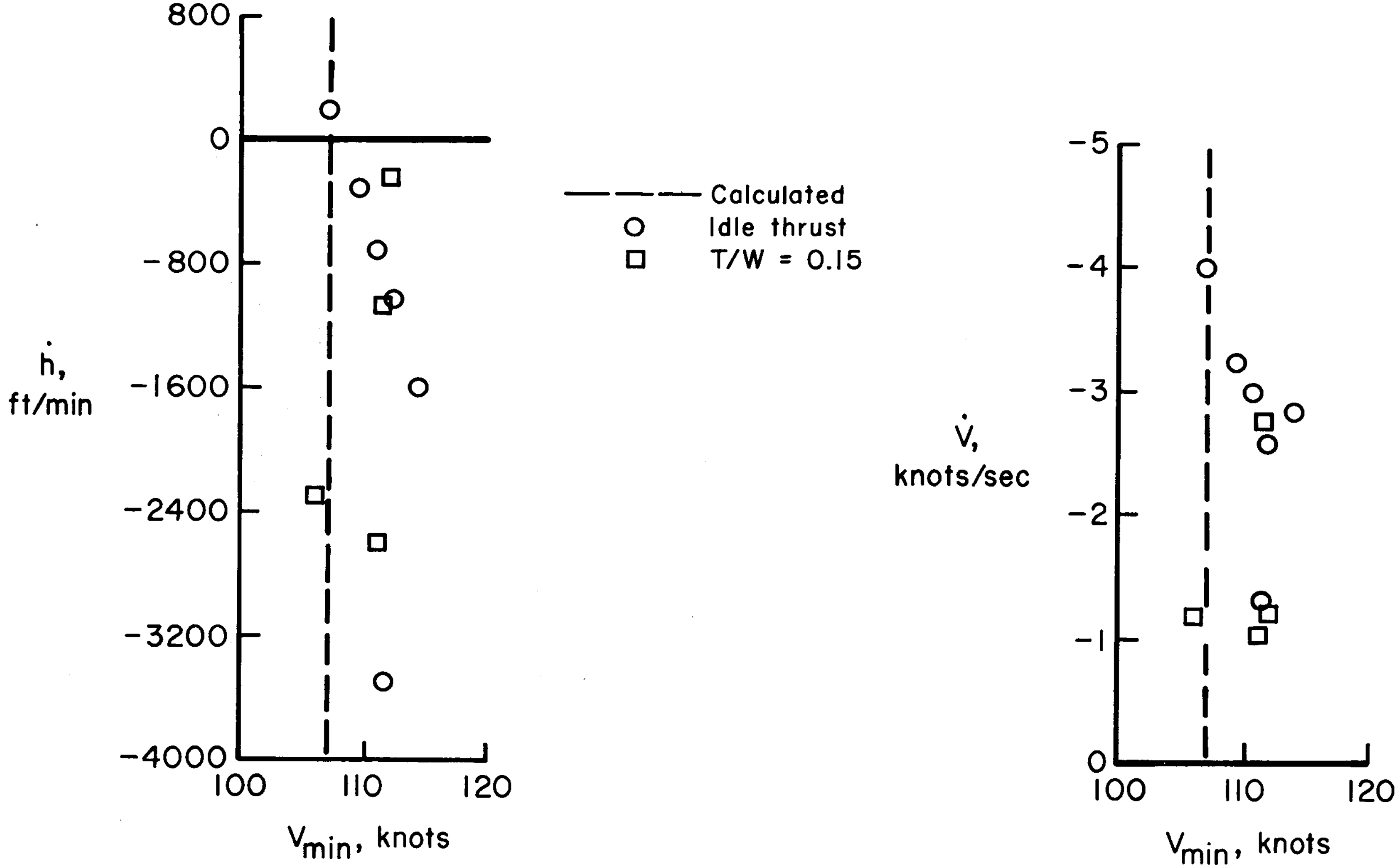


Figure 7.- 1 g normal-acceleration maneuver for the F5D airplane with an initial rate of descent. Idle thrust; 18,700 pounds gross weight. Accelerometer mounted along body axes.



(a) Effect of rate of climb.

(b) Effect of deceleration.

Figure 8.- Summary of the 1 g minimum-speed data for the F5D airplane. V_{min} corrected to 20,000 pounds gross weight. Accelerometer mounted along body axes.

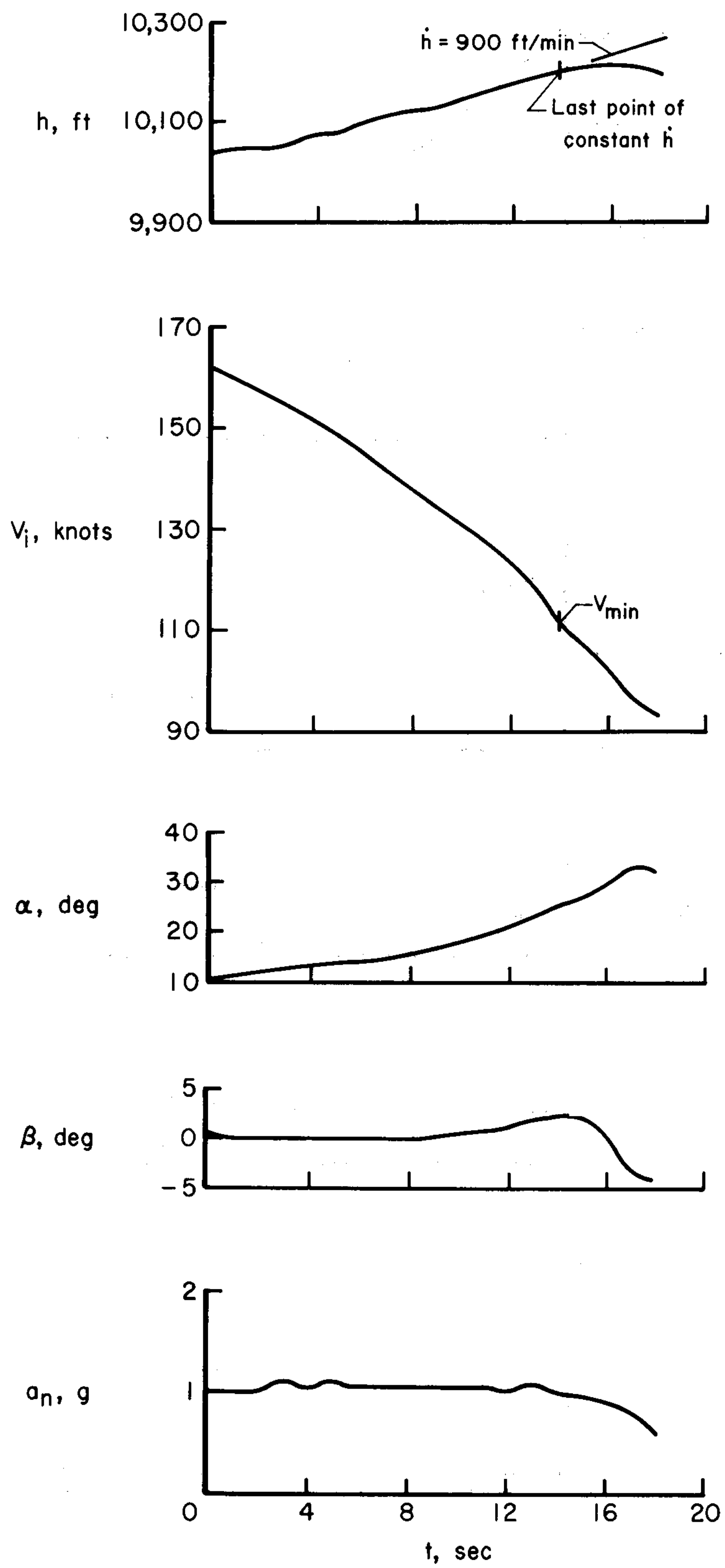


Figure 9.- Constant-rate-of-climb maneuver with the F5D airplane. Idle thrust; 20,300 pounds gross weight.

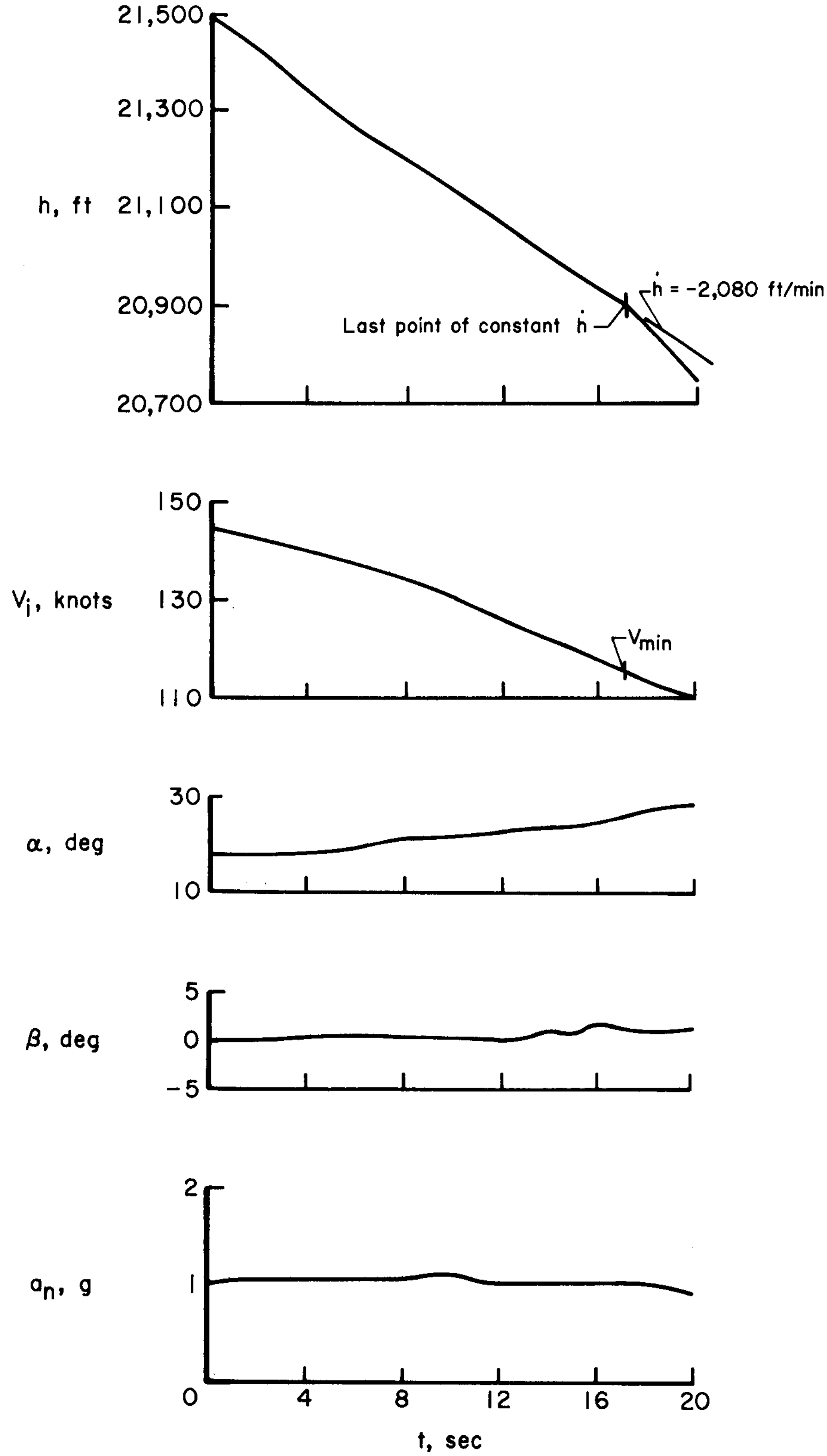
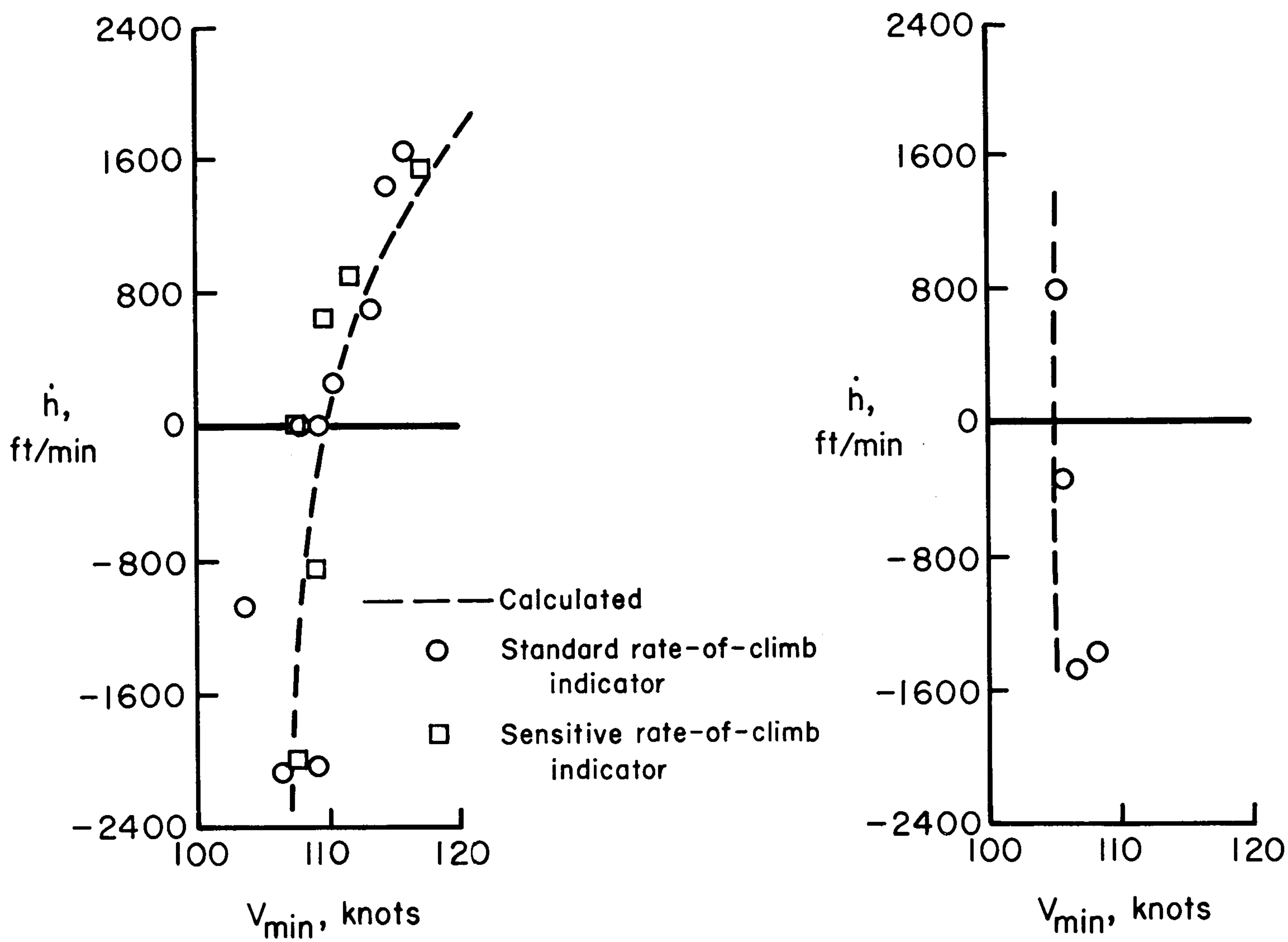


Figure 10.- Constant-rate-of-climb maneuver with the F5D airplane. Idle thrust; 23,500 pounds gross weight.



(a) Idle thrust.

(b) T/W = 0.15.

Figure 11.- Summary of rate-of-climb maneuvers for the F5D airplane with two thrust-weight ratios. V_{min} corrected to 20,000 pounds gross weight.

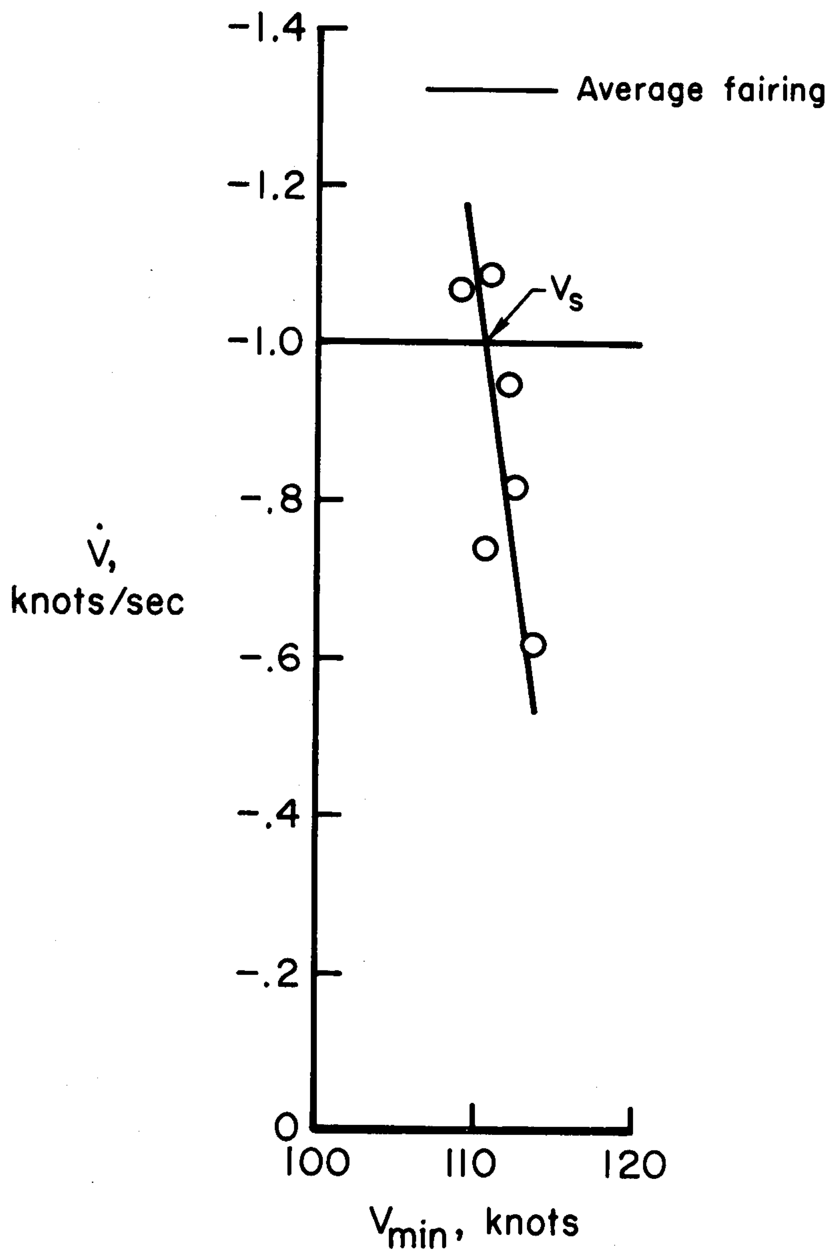


Figure 12.- CAR stall-speed analysis for the JetStar airplane. V_{min} corrected to 30,000 pounds gross weight; clean configuration; idle thrust.

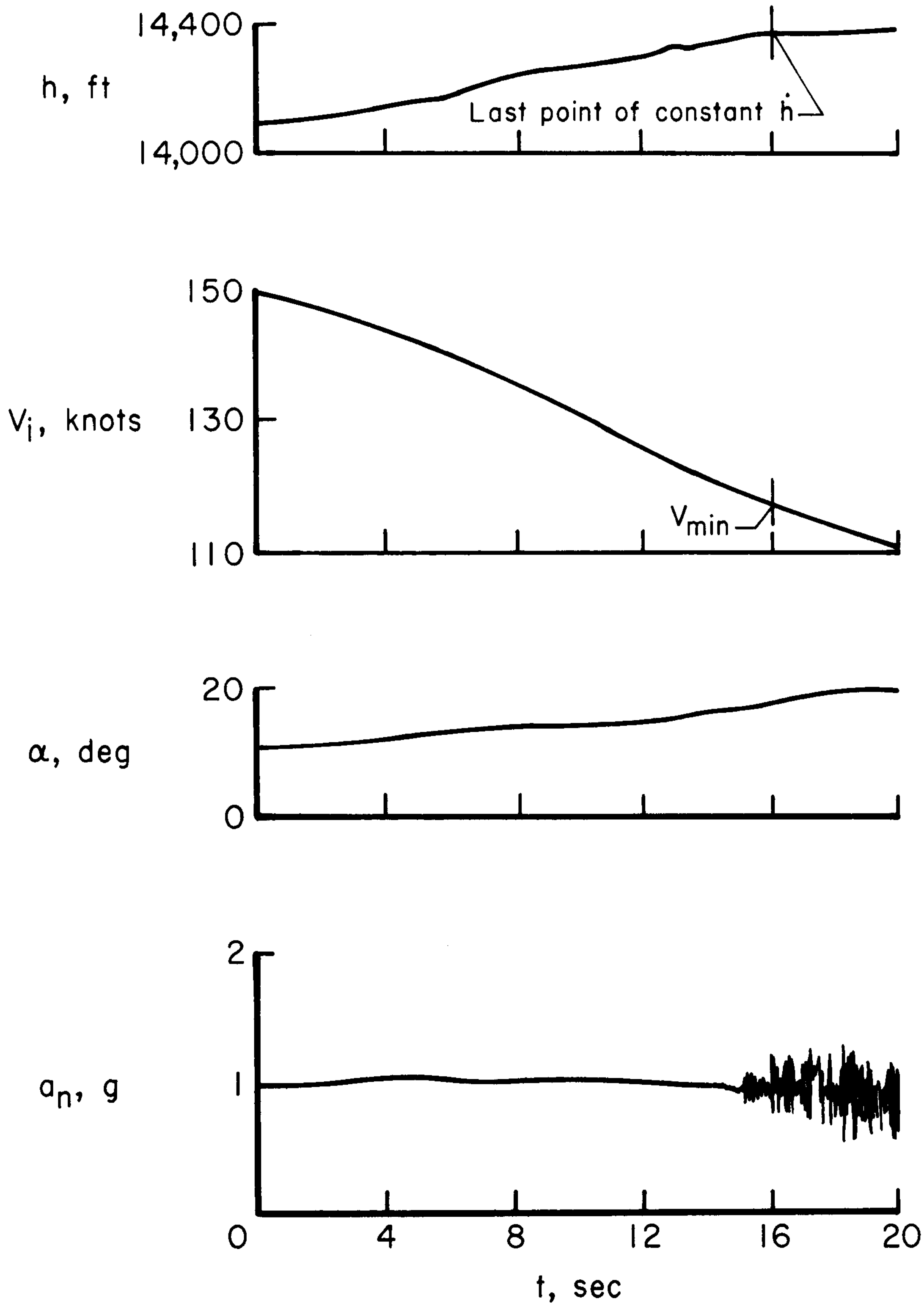


Figure 13.- Constant-rate-of-climb maneuver with the JetStar airplane. Clean configuration; idle thrust; 33,800 pounds gross weight.

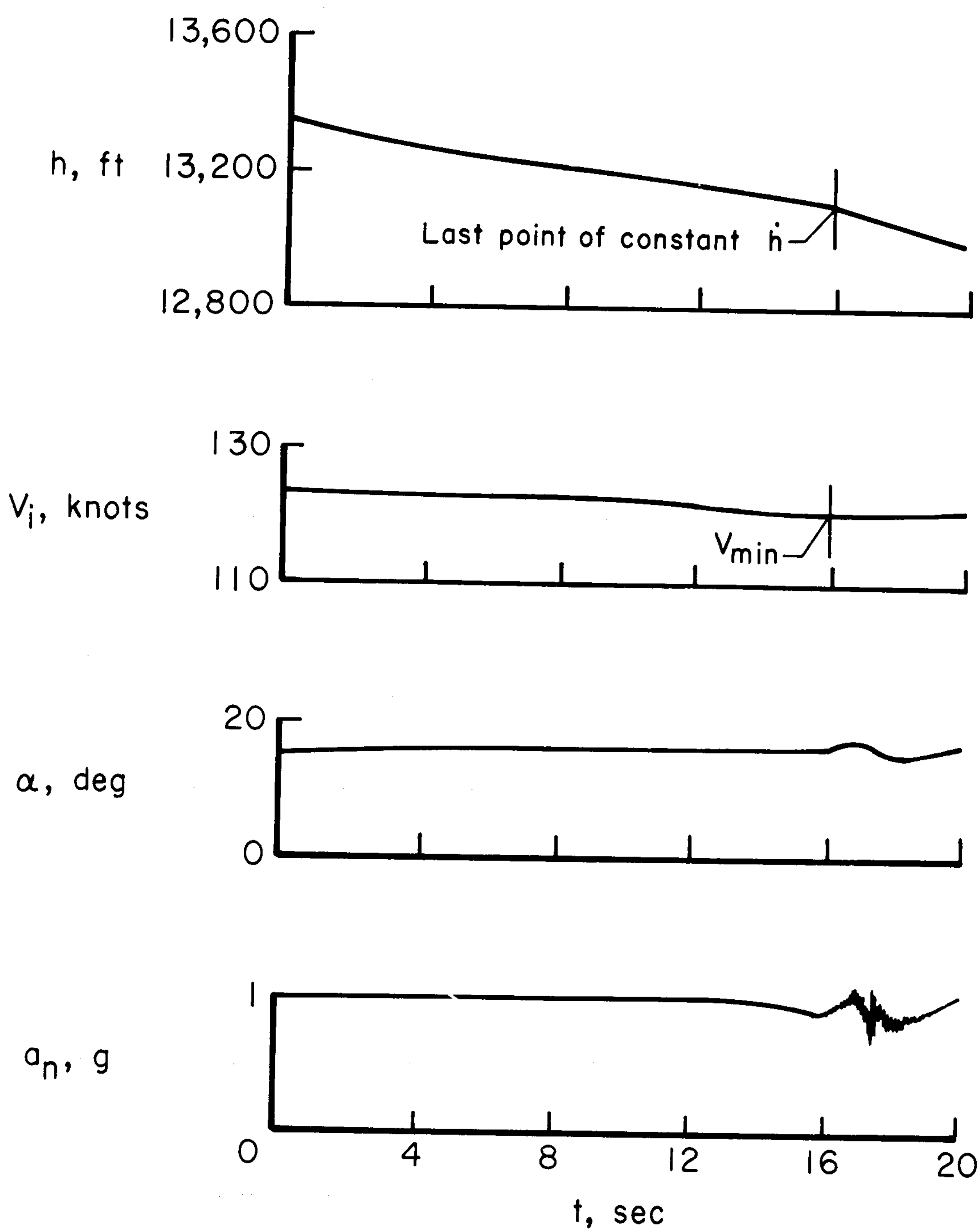
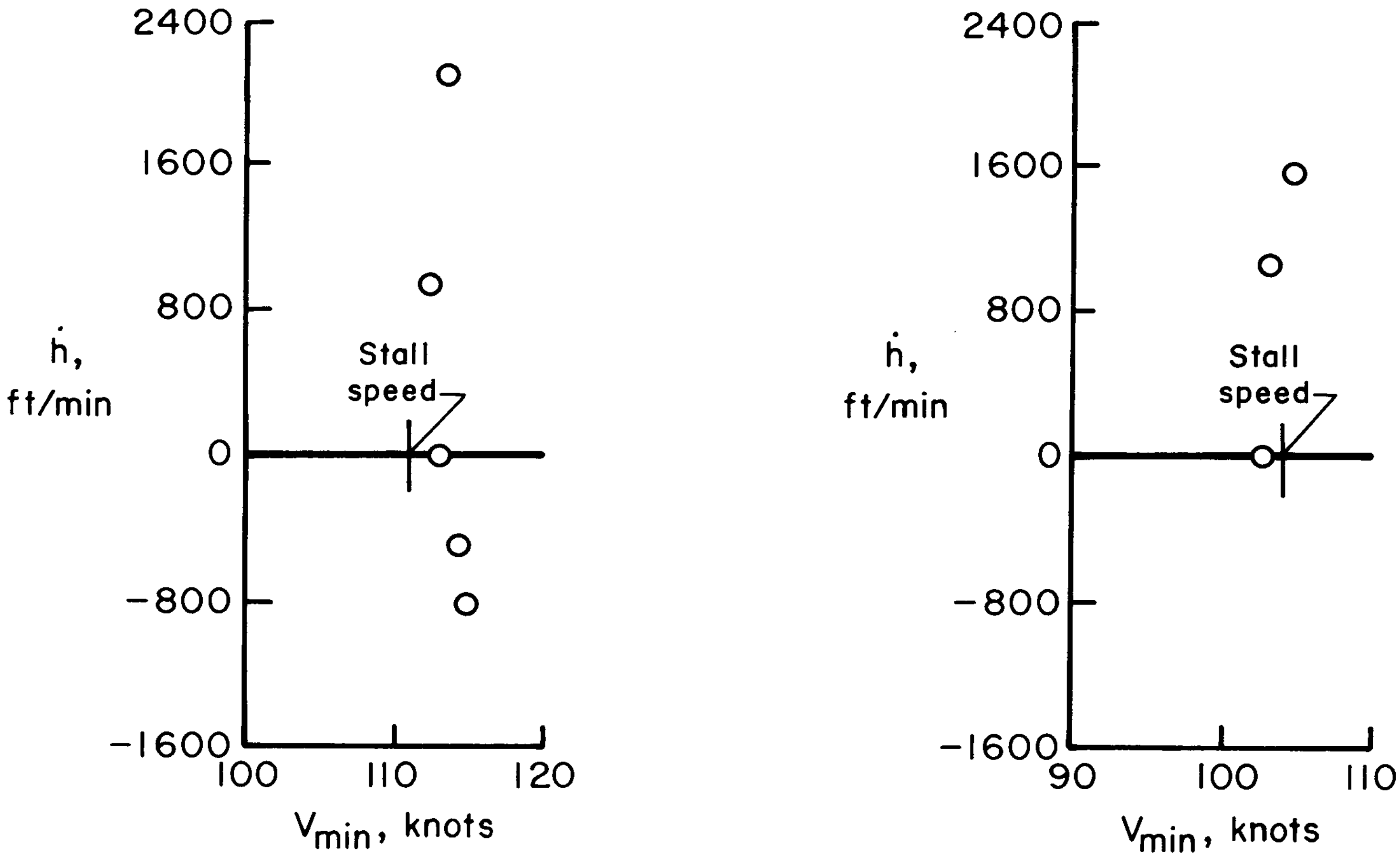


Figure 14.- Constant-rate-of-climb maneuver with the JetStar airplane. Clean configuration; idle thrust; 33,300 pounds gross weight.

NASA-Langley, 1964 H-344



(a) Clean configuration.

(b) Approach configuration.

Figure 15.- Summary of the idle-thrust, constant-rate-of-climb maneuvers for the JetStar airplane. V_{min} corrected to 30,000 pounds gross weight.

NASA TN D-2337
National Aeronautics and Space Administration.
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